A DESCRIPTIVE ANALYSIS OF THE DESIGN AND CONSTRUCTION OF AN EFFICIENT GAS-FIRED DOWN-DRAFT KILN

A Report
Presented to
the Faculty of the Graduate School
The University of Minnesota

In Partial Fulfillment
of the Course Requirements for Art Education 295,
Problems in Art Education

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April 1965

TABLE OF CONTENTS

PREFACE

The objective of this paper is to present, in a logical order, suggestions concerning design and construction of a gas-fired down-draft ceramic kiln with the potential of firing economically and efficiently from cone six to cone ten.

The basis for the conclusions in this study are remarks received from teachers and potters who have or are constructing this particular type of kiln. Also included is the ceramics department at the University of Minnesota, Duluth, (where there are two such kilns in successful operation at this time) and the personal experiences of the ceramics instructor, Mr. Glenn Nelson, and myself.

At this time I would like to thank the Art Department at the University of Minnesota, Duluth; the head of the art department, Dr. Arthur Smith, Mr. Glenn Nelson and all of the potters who have so generously given me much of their time and knowledge to make this study possible.

INTRODUCTION

This paper will be concerned with the construction, proportions and design of a gas-fired down draft kiln.

Basically there are two types of kiln designs: (1) up-draft kilns and (2) down-draft kilns. Although this paper is concerned with the down-draft kiln, it seems well to discuss briefly each type and to give a general idea of why the down-draft kiln construction is preferred to the up-draft kiln.

Generally, the up-draft kiln works on the theory of conduction. The fire-box is placed below the firing chamber, and the heat passes up the sides and out the flue located at the top. This is one of its most serious disadvantages in that the floor of the kiln is invariably hotter than the top of the kiln chamber. In some cases this difference in temperature can be as much as one or two cones (fifty to one hundred degrees) depending upon the size of the firing chamber. It is true that many kilns have a slight temperature variance; however, the wide variance presents many problems in glaze firings (especially in school situations). Also, it might be noted that because of the direct impingement of the flames on the floor and floor supports they tend to deteriorate rather rapidly making it necessary to check and replace them more often. Despite these rather basic disadvantages, this type of kiln is built by a number of commercial companies with the college or university market in mind.

Commercially built kilns are usually reliable. However, the basic high cost plus the shipping charges make the purchase of such equipment quite expensive. Expensive in this sense is not to suggest that a ceramics department could not afford to purchase a commercially built kiln. If the department can build the kiln, it can save a considerable sum of money. This savings could then be used for the purchase of other studio equipment and supplies.

On the other hand, the down-draft kiln tends to be simple in construction and more efficient in firing. Basically, the theory governing this type of kiln is that the flame is introduced into the fire box and channelled upward by the baffle walls. As it collects at the top of the kiln it is forced down by the combination of two internal functions: (1) the constant pressure of gases being introduced by the burners and (2) by the suction of the chimney, which draws the heat down and out the exhaust exit.

From this description, it is clear that from the direct downward flow of heat through the firing chamber there is maximum use of the B.T.U.'s produced by the burners. In addition, the down-draft design is quite flexible. Because of the simple construction of the down-draft kiln design, changes and alterations can be made to suit the operator. The down-draft kiln design has the added feature of being adaptable to a single fuel or a combination of fuels (ex.: combination of wood and gas). The down-draft kiln design also works more effectively as a salt kiln than an up-draft would, because of the presence of an exposed flame in the firing chamber. An open flame is essential to volatilize the rock salt crystals which are introduced either through the burner ports or a port in the roof of the kiln. For more information concerning the salt glazing technique see literature specifically written on this subject.

CHAPTER I

DEFINITION OF THE PROBLEM

Pottery kilns have been designed and built by craftsmen and individual potters for thousands of years. However, with the advent of the industrial revolution, the local craft of pottery-making has given way to the machine. Except for a few commercially-built kilns, kiln building has virtually died out. As a result, the literature written on this subject is almost nonexistent. The lack of pertinent details on kiln construction forces the individual potter to purchase an expensive commercial kiln, or he can attempt to build his own by the trial-and-error method. Unfortunately, both solutions are often impractical -- one, because of the expense and the other, because of inefficiency.

I. THE PROBLEM

Statement of the Problem. It was the purpose of this study to: (1) to present methods, techniques and conclusions of professional potters and teachers which were determined by a questionnaire; (2) design an efficient gas-fired down-draft kiln suitable for firing stoneware pottery; (3) discuss and develop sound techniques of construction; (4) develop a formula that will enable the designer to determine how many B.T.U.'s are required to heat one cubic foot of space in the firing chamber of a down-draft kiln to reach stoneware temperatures.

Importance of the study. The kiln represents the most important and expensive piece of equipment needed by the potter. The quality of his work is directly related to the efficiency of his kiln.

Commercial kilns are expensive for the potter to purchase. Also there seems to be some question as to how much the individual really understands about the kiln. By presenting a paper concerned with design and construction it is hoped that the student will gain the confidence needed to build a kiln or redesign and repair an old one.

The objective of the study was to sample many types of down-draft kilns; and from these designs, develop a kiln utilizing all of the best features which they had to offer.

CHAPTER II

REVIEW OF QUESTIONNAIRES USED IN THIS STUDY

There is very little factual material written concerning the problems in designing and constructing a gas-fired down-draft kiln. The backbone of this study will rely on the comments and suggestions of recognized potters and teachers with experience in this area. A questionnaire was used to obtain the information for this study; the results of which are summarized here. A sample of the questionnaire will be found in Appendix #B.

Department of Art
Scripps College
Claremont, California

<u>Construction:</u>

Brick	Inside lining Insulation	2400° (two courses) 200°
Draft	Direct Control behind kiln in stack	
Stack	Fifteen feet high	
Baffle wall	Adjustable to load	
Burner ports	Size: Four and one-half inches square	

Burners:

B.T.U.'s of each	Unknown
Type	Homemade natural draft
Number	Four
Number of inches from ports	The tip is inside the port

Firing Characteristics:

Preheat	Two hours
Number of hours to complete firing	Eighteen to twenty hours to cone ten to eleven. The firings are generally even.

Fine Arts Department
Indiana University
Bloomington, Indiana

Construction:

Brick	Inside lining	
	Insulation	Loose insulation
	Outside layer	Common red brick
Draft	Direct	
	Control	Damper in stack
Stack	Seventeen feet high	
Baffle wall	Small free-standing in front of burners; fourteen inches high	
Burner ports	Size: seven inches square	

Burners:

B.T.U.'s of each	Unknown
Type	Unknown
Number	Four
Number of inches from ports	Permanently attached inside port

Firing Characteristics:

Preheat	Four to six hours
Number of hours to complete firing	Twenty hours to cone seven

Carnegie Tech.
Pittsburgh 13, Pennsylvania

Construction:

Brick	Inside lining	2600°
	Middle layer	2400°
	Insulation	2400°
Draft	Hood type	
	Control	Damper at the top of the kiln
Stack	Fifty feet high	
Baffle wall	Installed to suit load	
Burner ports	Size: four and one-half inches in diameter	

Burners:

B.T.U.'s of each	One hundred twenty-five thousand B.T.U.'s per hour
Type	Forced draft
Number	Two
Number of inches from ports	Permanently attached inside port

Firing Characteristics:

Preheat	Overnight
Number of hours to complete firing	Twelve hours to cone 8

The size of the firing chamber is about twenty-seven cubic feet with a slightly arched roof. This design fires under a sub-floor making this entire area into a fire box. The two burners are offset and opposed. The heat rises along the two walls opposite the burners and is vented at floor level. It is cold near the door and hot in the back corners. Also, the operator has great difficulty equalizing the internal temperature.

Kansas State University
Manhattan, Kansas

Construction:

Brick	Walls are constructed of two layers of twenty-three hundred degree brick with the floor and fire boxes of hard refractory brick.
Draft	Direct

Stack	Twelve feet high
Baffle Wall	Thin pieces of fire brick are placed in front of burner ports to diffuse direct flame. The height is nine and a half inches.
Burner ports	Size: two and one-half inches square

Burners:

B.T.U.'s of each	One hundred thousand B.T.U.'s per hour
Type	Atmospheric inspirator
Number	Three
Number of inches from ports	One and one-half to two inches

Firing Characteristics:

Preheat	One hour
Number of hours to complete firing	Sixteen hours to cone 8; twenty to twenty-one to cone 10.

The dimensions of this kiln measure about fifteen cubic feet. It incorporates a number of unusual features. It is entirely built by loose brick construction. Its main attribute is that it possesses an extremely even temperature throughout. This is maintained by the use of burners attached to rubber hose. With this method the burners can be moved from port to port as provided in the basic design.

Department of Art
Michigan State University
East Lansing, Michigan

Construction:

Brick	Inside lining Insulation	Hard refractory 2000^{o} Exterior is covered with five inches of insulation.
Draft	Direct	
Stack	Unknown height	
Baffle wall	Nine inches high	
Burner ports	Size: two-and-one-half inches in diameter	

Burners:

B.T.U.'s of each	Unknown
Type	Homemade atmospheric
Number	Four
Number of inches from ports	Tip inside burner ports

Firing Characteristics:

Preheat	Eight hours
Hours to complete firing cycle	Twenty hours to cone 10-11

This is a relatively large kiln measuring forty seven cubic feet. Its basic design is quite traditional with good firing characteristics throughout.

Department of Art
University of Oklahoma
Norman, Oklahoma

Construction:

Brick	Inside lining	Hard refractory
	Middle layer	Vermiculite
	Outside layer	Common red brick
Draft	Direct	
Stack	Forty feet high	
Baffle wall	Yes	
Burner ports	Five inches square	

Burners:

B.T.U.'s of each	Unknown
Type	Atmospheric
Number	Four
Number of inches from ports	Installed in burner ports

Firing Characteristics:

Preheat	Overnight
Number of hours to complete firing	Ten hours to cone 9

This is of a conventional design. However, it is cool on the top and bottom. Therefore, the only workable area is in the center--thus wasting a great deal of usable space in the firing chamber.

School of Art
University of Washington
Seattle, Washington

Construction:

Brick	Inside lining Middle layer Outside	Regular fire brick 2000° brick Block insulation
Draft	Direct	
Stack	Eighteen feet high	
Baffle wall	None	
Burner ports	Size: nine inch half - circle	

Burners:

B.T.U.'s each	Two hundred thousand B.T.U.'s per hour
Type	Atmospheric
Number	Two
Number of inches from ports	Flush with port

Firing Characteristics:

Preheat	Overnight
Number of hours to complete firing	Twelve hours to cone 10

This is a sixty-cubic-foot kiln and has a number of very interesting features. Generally, the temperature is quite even--especially for its relative size. It fires under the floor through passages. Two vents are provided in the floor opposite the burners that are against the wall. The heat is forced up into the firing chamber toward the arched roof. Between the burner passages is an exhaust passage with the exhaust vent opposite the heat entry vents. Therefore a large loop of heat movement is created, and it works with excellent efficiency.

J. T. Abernathy
212 Santu Street
Ann Arbor, Michigan

<u>Construction:</u>

Brick	Nine-inch wall constructed of general refractory and insulating brick.
Draft	Two openings, four and one-half inches by nine inches, at the bottom of one wall.
Stack	No stack; vents into the room.
Baffle wall	None
Burner ports	Size unknown

<u>Burners:</u>

B.T.U.'s of each	Unknown
Type	Two-inch "sticktite" nozzles
Number	Six
Number of inches from ports	One-fourth inch

Firing Characteristics:

Preheat	Twenty-four hours
Number of hours to complete firing	Six hours to cone 9

This is a rather unique kiln. There are no baffles and no stack. The hot gases are exhausted into the room through a four-and-one-half by nine inch opening. This design is not the type that could be used in a classroom situation because of the method by which it is vented and also because of its size--three hundred forty-three cubic feet. However, according to the operator, this kiln fires out quite evenly.

Department of Ceramics
Toledo Museum School of Design
Toledo, Ohio

Construction:

Brick	Scrap brick throughout
Draft	Direct
Stack	Twenty feet
Baffle wall	Adjustable to suit the load
Burner ports	Size: three inches outside diameter and seven inches inside

Burners:

B.T.U.'s each	Three hundred seventy-five thousand B.T.U.'s per hour

Type	Homemade inspirator
Number	Two
Number of inches from ports	Movable for better control

Firing Characteristics:

Preheat	Two hours
Number of hours to complete firing	Eighteen hours to cone 10

This kiln is a catenary arch design. Generally, it follows the conventional style of down-draft kilns with baffle walls and exhaust passage. The big difference is that the burners are placed one on each side, opposed. Its firing cycle is quite constant.

Department of Art
State University of Iowa
Iowa City, Iowa

Construction:

Brick	Nine-inch wall built of twenty-three hundred degree fire brick using loose brick construction.
Draft	Direct
Stack	Eighteen feet
Baffle wall	Adjustable to suit load
Burner ports	Size: two and one-half inches by four and one-half inches

Burners:

B.T.U.'s	One hundred fifty thousand B.T.U.'s per hour
Type	Homemade forced draft
Number	Four
Number of inches from ports	Tip is inside ports

Firing Characteristics:

Preheat	None
Hours to complete firing cycle	Fourteen to nineteen hours to cone 10

This kiln is quite large, measuring forty-nine cubic feet. Generally, it follows the conventional design of down-draft kilns. Its main innovation is in the loose brick construction. The builder states that its firing cycle is relatively even with a tendency toward being hot on top. This can be controlled by the operator.

Department of Art
University of Georgia
Athens, Georgia

Construction:

Brick	Inside lining Middle layer Outside layer	Refractory brick Insulating brick Common red brick
Draft	Direct	
Stack	Nineteen feet high	
Baffle wall	Permanent	
Burner ports	Six-and-a-half inches square	

Burners:

B.T.U.'s each	Unknown
Type	Homemade
Number	Four
Number of inches from ports	Inside ports

Firing Characteristics:

Preheat	None
Hours to complete firing cycle	Thirty to thirty-nine hours to cone 9

This is designed on the lines of a conventional down-draft kiln. Unfortunately, the firing characteristics are quite poor. It is hot on top and in the back--with great difficulty in equalizing the firing.

Department of Design
New York State College of Ceramics
Alfred University
Alfred, New York

Construction:

Brick	Inside lining	Medium duty fire brick
	Middle layer	Two thousand degree brick
	Insulation	Common red brick
Draft	Direct	
Stack	Two feet high	

Baffle wall	Twelve inches high
Burner ports	Size: four inches by five inches

__Burners:__

B.T.U.'s	One hundred thousand B.T.U.'s per hour
Type	Atmospheric
Number	Six
Number of inches from ports	Inside port about four inches

__Firing Characteristics:__

Preheat	None
Hours to complete firing cycle	Fifteen hours to cone 10

This is a conventionally designed down-draft kiln. It is a type that is identified with Harry Radcliff. Its firing characteristics are quite good although far from perfect. If the operator is sensitive to its hot and cool areas, he can place the glaze ware accordingly.

Art Department
University of New Mexico
Alberquerque, New Mexico

__Construction:__

Brick	Inside lining	Twenty-six hundred degree brick
	Insulation	Soft insulation brick
		The entire kiln is covered with a steel shell.

Draft	Direct
Stack	Four stacks each eight feet high
Baffle wall	None
Burner ports	Size: One and one-fourth inches

Burners:

B.T.U.'s of each	Unknown
Type	Forced draft
Number	Two
Number of inches from ports	Inside the burner ports

Firing Characteristics:

This kiln has an eighty-cubic-foot capacity. The top eighteen inches is the combustion chamber rather than the bottom as in most kilns. The heat is then forced into this area, drawn down to the floor, and vented by four stacks: two in front and two in back. The forced draft burners are run by a five-horse power electric motor. The door represents the entire front wall which rolls out on a center I-beam.

The kiln is a new patented design built by MKB Industries, Inc. of Denver, Colorado. The total cost of construction was about sixty-five hundred dollars.

By analyzing the results of the survey taken of ceramics teachers and professional potters, it becomes clear that there are relatively few common methods used to solve the problems of a gas-fired down-draft kiln. In most cases the designs discussed in the survey represent individual solutions to kiln construction and basic design. The exception is the patented commercially-built kiln being used at the University of New Mexico.

In designing the kiln to be discussed in this paper, I have selected what I consider to be the strongest points of all the down-draft kiln designs made available to me. It is my hope in doing so to arrive at one basic down-draft design that will have excellent firing characteristics as well as being relatively inexpensive to construct.

CHAPTER III

GENERAL POINTS TO CONSIDER PRIOR TO CONSTRUCTION

Since there is little information written concerning the construction of down-draft kilns, it will be the objective of this paper to take each section of a kiln design and discuss it at length. It is hoped that this discussion will result in a series of valid conclusions that can be transferred to the basic design of any kiln of this type.

Primarily, studio kilns are built either from a design handed down from potter to potter or by the trial-and-error method. In some cases these kilns work very well. However, in just as many instances the result is a kiln, not only inefficient in heat transfer but with a temperature variance of two or three cones.

Basically, a potter's kiln is a relatively simple instrument constructed of fire brick and insulation with its primary source of heat derived from gas, wood, oil or electricity. For the purpose of this paper, I have chosen natural, manufactured or bottled gas as the primary source of heat because of its availability, economy and potential for obtaining variety in the finished work.

The discussion is centered around the construction of one simple down-draft kiln designed by the author of this paper. The main problems encountered in this design tend to be universal; thus, the solutions might be transferred to kilns with larger or smaller interior proportions.

Before the design and construction of any kiln can proceed there are a few basic facts which must be discussed. Generally, to construct a high-temperature kiln, the following two basic types of fire brick are required: (1) refractory brick and (2) insulating brick.

The high-temperature refractory brick is used to construct the inner lining of the firing chamber and the fire boxes because of the intense heat in these regions. The selection of the temperature range of this brick should be in direct relation to how high the finished kiln is intended to fire. The interior lining should be of sufficiently high temperature brick to insure that its maximum temperature will never be reached or exceeded. This is important to the total life of the kiln. In the case of the kiln that is discussed in this paper, the plan calls for Babcock and Wilcox K-28 or refractory brick which will withstand temperatures of a maximum of 2800 degrees F. according to the manufacturer's specifications. This particular type of refractory brick is quite hard and dense in its basic composition; therefore, it transmits heat rapidly. It is for this reason that an outer layer of insulating brick is required. (Babcock and Wilcox Refractories manufacture all the types of brick referred to in the remainder of this paper.)

The brick used for insulation is a rather high-grade, light brick that is quite porous. Because of its porosity this brick provides excellent insulation. In many kilns of older design and construction the plans call for a thirteen-inch wall which consists of a hard refractory lining, a thick layer of insulation covered with a third layer of common red brick. However, by using the new type of light insulation brick, a wall seven inches thick is sufficient to maintain the kiln's efficiency.

Generally, it is sound planning to build a kiln from all new high-quality fire and insulating brick. There are many good manufacturers of fire brick; two reputable companies are A. P. Green and Babcock and Wilcox Refractories.

The reader might be interested here in regard to the use of old fire brick in the construction of a high-temperature kiln. It is difficult to build an economical kiln out of used fire brick. Usually, they are in bad condition and extremely hard, and because of this they have little or no insulative quality. However, if the bricks are in extremely good condition they may be used in the fire box or the interior lining where the insulative quality is not critical, but care must be taken that they are of sufficient quality to withstand the extreme temperatures of this region.

Cracking of the walls in the kiln is unavoidable. The problem is not to eliminate it but to minimize its destructive effects. As the firing chamber increases in temperature, the lining begins to expand. Provisions must be made to allow this expansion to occur. This is not necessarily a problem when the kiln is constructed entirely of brick. Even though each brick may be slightly uneven in its coefficient of expansion and contraction, the seam between each brick acts as an expansion joint, relieving the pressure in many areas at the same time.

Should the lining of the kiln be constructed of a castable refractory, expansion joints must be designed into the basic construction. If this is not done, the lining will crack and deteriorate at a rapid rate.

As a general point of consideration, simplicity is the rule. A simple design is easy to construct, and when put into operation is easy to repair. Each component of the kiln should be alterable without the necessity of dismantling the entire structure.

The last point of preliminary consideration should be that of the kiln's size and proportions.

Usually, it is not wise to build a studio kiln that is too large, especially if it is the only one in use. The most convenient sizes seem to be in the range of fifteen to thirty cubic feet. If the kiln is large, it takes too much work to fill it; thus, many firings are made with less than full loads. This is not consistent in attempting to maintain even firings, for a kiln will perform in direct relationship to the size of the load. The reverse of this problem is a kiln that is too small. In this case, it is difficult to keep ahead of the student production. However, in terms of consistent heat distribution a smaller kiln is preferred.

The interior dimensions of the kiln should be square. This is not a law of kiln design, but it does tend to equalize heat distribution. To some extent, this concept can be varied; but it should be recognized that in varying the dimensions some provisions must be made in the heat flow to compensate for this change. An example of varying the dimensions is to have the roof higher than the kiln depth. In this case the heat must be forced to the crown and sufficient draft must be provided to pull it down in order to maintain an equal temperature. In essence, it is important to understand the nature of interior dimension changes and how to make the necessary adjustments to compensate for them.

The kiln design discussed in this paper is of relatively square proportions. The only reason for it not being exactly square is because it is proportioned to eliminate, as much as possible, the cutting of brick.

With the above items duly considered, the discussion can now turn to the problems of the actual kiln construction.

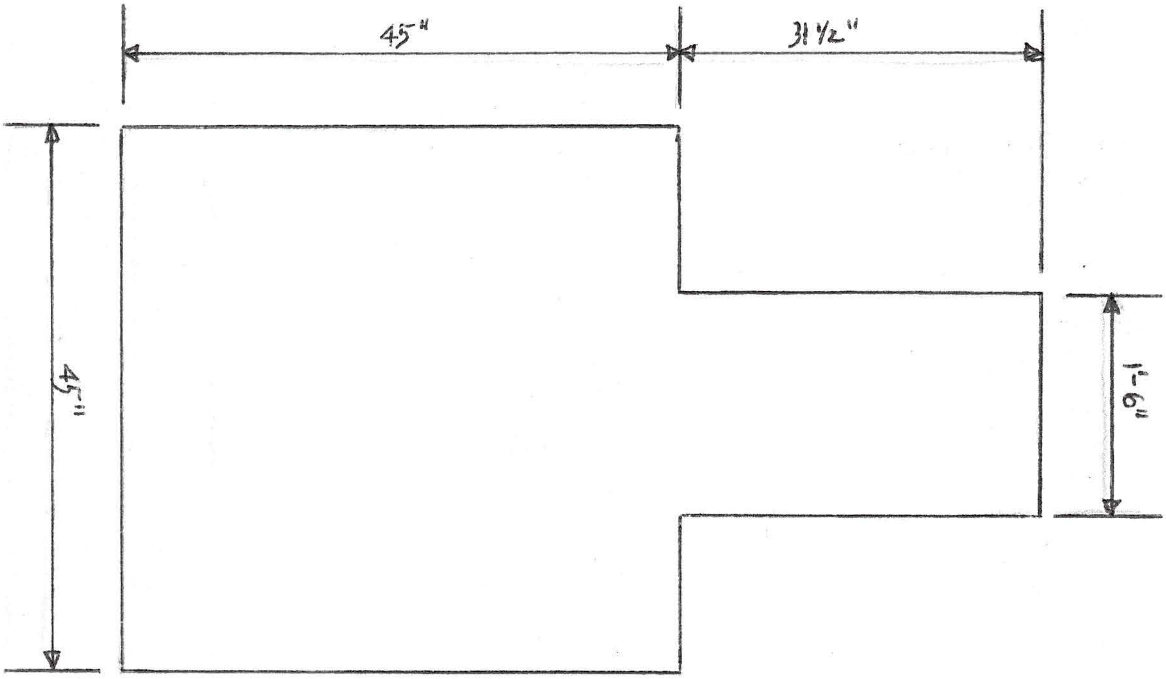
CHAPTER IV

PROBLEMS AND SUGGESTED SOLUTION IN THE CONSTRUCTION OF THE CONCRETE AND BRICK BASE OF THE KILN

The first and most important problem to discuss is the kiln base. The absolute base should consist of six inches of steel reinforced concrete. It may be that if the kiln is to be constructed directly on the floor, a four-inch slab would be sufficient. However, a slab that is poured directly on the floor makes the finished kiln quite low and inconvenient to load. It is therefore recommended that the slab be poured and raised off the floor about twenty inches. This can be done by the use of concrete blocks as legs or supports.

A twenty-inch elevation will make the finished kiln easy to load and will give easy access to the spy holes, burners and draft control. It is important to design a kiln that is easily accessible, because of the constant care it requires during the firing cycle.

The construction of an eighteen-cubic-foot kiln requires a reinforced concrete base that measures forty-seven inches across the front by forty-seven inches on each side. Along the back, where the chimney will be installed, provisions must be made for support. The chimney section of the base measures thirty-three and one-half inches by twenty inches and is poured as part of the main section directly in back of the center to form one complete unit six inches thick. The base supports the entire kiln and its chimney. The exact dimensions and form of the reinforced concrete base is shown in the following sketch.



After the reinforced concrete base has been poured and allowed to harden the first layer of K-16 insulation bricks can be put into place. This is one solid flat layer--four-and-one-half bricks wide and five bricks long. The chimney area is three bricks long by two wide. An alternative to using K-16 insulating brick is the substitution of common red brick. If this is done, remember that fire brick and building brick do not have the same dimensions. The first two layers of K-16 bricks are put into place, one on top of the other, taking care to half-lap the seams for better stability. The third layer is constructed with K-23 insulating brick which is laid using the same method as the first two layers. The reason for using a higher-temperature brick here is its close proximity to the main floor which will carry the two fire-boxes and the exhaust passage. The bricks in the base need not be mortared together. The sheer weight of the completed kiln will keep them in place.

The fourth layer of brick is a combination of K-23 and K-28. The outside course of K-23 is the actual base for the insulation wall. The inside courses are of Babcock and Wilcox high temperature K-28 fire brick. This flat layer is the absolute floor of the firing chamber and must be constructed of high-temperature fire brick. These first four layers of brick are for insulation and provide a sound kiln base. It is a good idea not to skimp on this part of the kiln, even though it does not come into direct contact with the heat.

There are alternatives when it comes to insulating the floor of the kiln because the floor does not have to be solid brick. Another solution to the problem might be to construct the outer ring of insulation brick, and then fill the open area in the center with crushed fire brick or a similar material; however, if this is done some type of castable material should be poured over the crushed insulation to give it stability and to make a level surface on which to continue the construction.

In the design under consideration, the base is constructed of four complete layers of brick. It may be that three layers of brick would be sufficient for proper insulation and stability. This would cut construction cost; however, it is important to provide a good substantial base on which to build the kiln.

CHAPTER V

PROBLEMS AND SUGGESTED SOLUTIONS IN THE CONSTRUCTION OF THE FIRE BOX AND EXHAUST PASSAGE

The next three courses of brick will house the three most important elements of the kiln. They are the two fire boxes, the sub-floor and the exhaust passage.

The construction of the outside insulation wall of K-23 brick should be started first. The interior wall consists of K-28 brick placed on their two-and-one-half-inch sides. Each course of both types of brick goes completely around the kiln, except in the area of the exhaust exit where a four-by-five-inch opening is left to connect with the chimney. (This aspect will be covered in detail later.)

The next point is the installation of the burner channels. They consist of a row of K-28 refractory brick laid on their two-and-one-half-inch sides along the side walls. Then measure in toward the center approximately five inches, and place another row of K-28 bricks on their sides from front to back. One inch from this row another course is installed from front to back. (See Appendix A.) With this step completed, the sides and the bottom of one fire box is completed. Next, duplicate the same procedure on the opposite side. With the completion of this step, both fire boxes and the exhaust passage are formed.

The sub-floor can now be laid into place. To begin building the sub-floor, lay one full brick across the large five-inch-wide passage with another full brick laid sidewise to cover the small passage. This is repeated on both sides, using a total of eight whole bricks per side. When this is finished, the sub-floor is complete except for a nine by four-and-one-half-inch opening which is left in each corner opposite the burners as a vent for the fire boxes. This opening permits the heat to rise into the firing chamber. The vents may be a little large, if so, they can later be reduced to a size just large enough to permit efficient operation. These particular joints should not be mortared.

Under the sub-floor there are two fire boxes of about four-and-one-half inches by five inches, plus a draft passage four inches wide by seven inches deep which is open the entire length of the firing chamber. A passage of these proportions should insure sufficient draft.

There is no set rule to follow in designing a draft passage. The research for this paper indicates that there are as many innovations of this aspect of kiln design as there are kilns. However, it is essential that adequate draft be provided. In this particular design, the channel is deeper than it is wide. Many potters said that their kiln floors were cold, and the only way they could compensate for it was to raise the first shelf about six inches, which represents a waste of valuable space. Therefore, by making the draft passage deeper, it will pull the heat down, establishing a smoother draw and a more even temperature.

In a larger kiln the draft arrangement will have to be proportionately enlarged. A general rule is to over-estimate the draft slightly, because the operator has control over the gas flow with damper adjustments.

The draft exit port should be smaller than the draft passage. The reasoning behind this is that the smaller opening acts as a heat retainer which gives a more positive draft control. In this case the exit port is four by five inches.

Another consideration is that the exit port should be smaller than the actual chimney. Making it smaller sets up a situation whereby the exhaust rushes to fill the larger area in the chimney, thus, insuring a constant even draft.

It is advisable to provide an auxiliary port opening into the draft passage opposite the chimney's exhaust port. This will be a valuable device for inspection during the actual firing. Also, when the kiln temperature drops below four hundred degrees, the plug can be pulled to facilitate cooling, a feature that will prolong the life of the kiln. Opening the kiln's door before the temperature has been sufficiently decreased forces the interior brick to contract rapidly, causing cracking and deterioration of the kiln. The auxiliary port is probably unnecessary in the conventional down-draft design because enough outside air is drawn into the firing chamber through the burner ports when the damper is opened. However, in the design under discussion, the burner ports do not open into the firing chamber, and this is why it is importan t to provide the port.

In summary, it is clear that all of the elements of the floor and exhaust region covered so far have a definite function. The floor plan is laid out to provide maximum use of space and also to enable the builder to change and repair any section of it with relative ease. The basic concept behind the design of such a heating arrangement is to provide even heat distribution by using both radiation and direct heat flow. Also, with this method it would help eliminate a rather common problem with down-draft kilns called "flashing" which occurs when the flame plays directly on the ware causing the glazes to shine excessively.

CHAPTER VI

PROBLEMS AND SUGGESTED SOLUTIONS IN THE CONSTRUCTION OF THE CHIMNEY

The chimney is one of the most important aspects of the kiln. The chimney houses the damper control and controls the draft of the kiln.

For maximum effectiveness the damper should be placed as close to the exhaust port as possible, although it will be workable placed almost anywhere between the exhaust port and the top of the kiln. If the damper is placed high in the chimney, this section of the chimney must be considered as part of the firing chamber. Placing the damper control close to the exhaust exit will tend to keep the stack cooler.

It is important to consider at this point the material to be used for the damper. In most cases a small silicon-carbide shelf is used. It should be considered that with the extreme heat passing from the firing chamber to the stack the shelf may crack. This is not a problem in itself; however, the broken piece will lodge itself in the flue and block the heat passage. If a shelf is used, it should slide in a horizontal fashion. If a steel plate is used, the plate will function well vertically. In this case, a pulley arrangement can be installed so that damper settings can be made and held.

The diameter of the stack is relative to the size of the firing chamber. If the stack is connected to only one kiln (fifteen to twenty-five cubic feet), a seven to nine inch diameter is sufficient. A good rule to follow is to provide enough stack to insure proper draft. The chimney is a relatively permanent fixture in most school situations, and is not easy to change when installed. Also, when additional kilns might be built, the chimney should be large enough to accommodate them.

Generally, in connecting the kiln to the main stack, there are two accepted procedures to follow: (1) by using a hood arrangement, or (2) by connecting the kiln directly to the chimney.

The primary reason for using a hood is to introduce room air into the stack during the firing cycle. This auxiliary air supply tends to cool the upper sections of the chimney. In a down-draft kiln the introduction of outside air in this manner tends to reduce the efficiency of the stack; therefore, it is advisable to connect the kiln directly to the chimney.

The stack length is not always under the direct control of the kiln builder, especially in a school situation. If the chimney is excessively long, a stack control should be installed near the top that can be operated from the kiln room. A long stack increases the gas velocity, which tends to cause irregular heating. In contrast a short stack will tend to prolong the firing cycle. If it is possible, the stack should be approximately fifteen to twenty feet high to provide adequate draft.

The above figures are not always true; there are kilns in operation which have a stack length of only two or three feet. At the other extreme, there are some kilns with a stack of fifty feet. These working examples are extremes and do not always display sound thinking on the part of their designers.

Atmospheric conditions will not have a great effect upon the drawing ability of the stack, unless there is extremely turbulent weather or strong prevailing winds. If the length of the stack is high enough to clear any immediate obstructions, it should draw effectively.

The construction of the stack need not be entirely of insulating brick. It is advisable to brick out from the kiln and up for about ten courses. From this point a transite tube may be used as long as it is protected from the weather. (Often the chimney is not constructed entirely of brick because of the additional expense.) The author has been successful using heavy-gauge galvanized stack material, which is relatively inexpensive and easy to work with, plus the fact that it withstands heat and weather well. The only problem with this material is that the stack gets very hot, so it must be kept from direct contact with inflammable materials. Also, where the stack goes through the ceiling, additional care should be taken to make it fireproof.

The outside opening of the stack should have a rain cover to prevent erratic down-drafts during the early stages of the firing cycle. At the University we have experienced down-drafts which were strong enough to blow out the burners. This is not a serious problem if the burners have safety equipment, but it is frustrating to discover that they have been blown out, and that the kiln is cold.

In general, the chimney does not present any real problems as long as it has sufficient height and diameter to efficiently vent the firing chamber.

CHAPTER VII

PROBLEMS AND SUGGESTED SOLUTIONS IN THE PLACEMENT OF THE BURNER PORTS

The next problem to consider is the location of the burner ports, their size, and their relative importance.

The burner ports of the design under consideration are placed alongside the chimney, one on each side (See Appendix A, Sec. "B-B"). They are placed about eleven and one-half inches from the edge of the kiln in to the center of the port, thereby corresponding directly with the fire box passages. The burner ports are about four inches square which gives sufficient secondary air to draw the flame into the fire box and provides for complete combustion. There is no rule governing the shape of the burner ports. I have chosen square ports because they are easier to build during the wall construction rather than waiting until the wall is completed, and then having to drill and file round ports.

It is important that the burner ports be strategically placed in order to give the flame an unobstructed flow to the vents at the other end of the passage. From here the heat rises into the firing chamber. The placing of the ports is especially important in this design.

The question may arise of whether or not the burner ports should be lined with high-temperature refractory (K-28) brick. In most cases this is not necessary, because the heat concentration is inside the fire box and not at the point of entry to the fire box.

The most important thing to consider when installing burner ports is that they are large enough to supply sufficient secondary air and to insure maximum efficiency of operation.

CHAPTER VIII

PROBLEMS AND SUGGESTED SOLUTIONS
IN THE CONSTRUCTION OF THE WALLS, DOOR AND ROOF

With the completion of the reinforced concrete slab, the base of insulating brick, the fire boxes, and the draft passage, the remaining wall and roof construction will move along rather quickly.

The interior wall is a continuation of the K-28 refractory brick used in the construction of the fire boxes. The lining is nine courses high, making the interior dimensions approximately thirty-three inches by thirty-one inches by thirty-one inches, or eighteen cubic feet of working space.

The exterior is constructed completely of K-23 insulating brick. This is a soft, light brick, very porous, providing excellent insulation. The use of this brick eliminates the need for constructing another outer layer of common red brick. This will reduce the total cost of construction.

There are two concepts concerning the use of mortar between the bricks. A number of potters simply stack the bricks loosely; permanency is doubtful using this method. In a graduate school situation, this is ideal because the graduate student is able to build and fire many experimental kiln models, and gains valuable experience. When a kiln is designed for use in a studio more permanent construction is probably preferred.

The mortar used in high temperature kiln building is not really a leveling material, rather it is a binding material, sealing the cracks between the bricks. To properly use this material, it should be mixed to the consistency of thick cream. The bricks are then soaked in water until they are saturated. The edges of the bricks which form the joint are then dipped into the mortar and then tapped into place.

In either method of construction it is important to join the inner refractory wall to the outer insulating wall. This is done by overlapping the bricks from one layer to the other. If this is not done, the inner wall will tend to separate, and eventually may even collapse.

Door construction can be accomplished by using either of two accepted methods. The easiest method is simply to brick up the door before each firing. A hinge-type door is the other method. This type of door is quite effective; however, its popularity in individually-built kilns has suffered somewhat because of its comparitive difficulty of installation, and this, in turn, tends to effect its general operation. To install a hinge door, a super-structure of steel must be constructed around the door opening and anchored well to the steel skeleton of the main kiln structure. The hinges are attached to the steel super-structure around the door, and the door is hung from these. With a large kiln having a large opening, a sliding door suspended from an "I" beam would be preferable to a hinge-type door. Because of the extensive steel work involved in this construction and the sheer weight of the door, the door's size is limited. From this description, it is clear why this type of door is not very popular with individually-built kilns.

The brick-type door takes a little extra time in closing, but it does have its advantages. By bricking up the door there are no limitations to the door's size. Also, in the case of the kiln under discussion the door is virtually one entire wall. Should repairs or alterations be required, the interior of the kiln will be easily accessible. The construction of the brick door is the same as in the walls of the kiln, an inside layer of K-28 fire brick on edge with an outer insulation of K-23 brick laid flat. With the completion of the door, the four walls, the inside fire boxes, the draft passage, and the exhaust system, the general construction is nearly complete, leaving only the roof.

Traditionally, kilns have had an arched roof. This type of construction tends to facilitate an even flow of the hot gases through the firing chamber. With the construction of an arch in the kiln roof, it becomes quite permanent, because of difficulty in dismantling. The roof construction can be accomplished by either purchasing brick specifically designed for this purpose, or by cutting the sides of common fire brick to form the arch.

In this kiln design the plans call for a flat roof constructed of K-28 refractory brick on end. The entire roof will take nine rows of eighteen and one-half bricks each. The bricks are suspended from chrome or common steel rods that pass through the upper one-third of the brick. The rods are threaded so that a steel plate and bolt arrangement can be installed to hold the bricks in place. The suspended brick roof is prefabricated and laid into place supported by the walls. During the first few firings, the bolts have to be adjusted to relieve the tensions set up by the expanding brick. The basic advantages of this type of roof are its relative ease of construction and its portability.

CHAPTER IX

THE SELECTION OF SIZE AND TYPE OF GAS BURNERS

The selection of the type and size of gas burners to fire any kiln is a matter of great consideration. The types of burners fall into two broad categories: (1) forced draft and (2) atmospheric. Both types are suitable, with the selection mainly depending on the size of the kiln to be fired.

Forced draft burners usually produce around two-hundred-fifty thousand B.T.U.'s per hour. The burner is equipped with a blower fan which forces the gas and air mixture down a long tube to the nozzle, where it is ignited. Using the fan forces the gases into the combustion chamber at a relatively high speed. This type of burner will increase the heat considerably, and will handle large loads.

In contrast, a natural draft or atmospheric burner is dependent on the size of the orifice, and on the gas pressure for the gas velocity. This type of burner has a primary air supply sucked in by the gas flow, goes down the venturi tube, and is ignited at the tip. In some cases the primary air supply can be controlled, but in most instances the burner is designed to supply enough air without control.

Basically, both forced draft and natural draft burners require a gas and air mixture to function. The main difference is that in a forced draft burner the gas and air mixture is forced by a fan, and in the atmospheric type the gas and air are sucked down the venturi tube by the gas pressure only. One more fact to consider is the relative cost of each. Because of the blower fan, the forced draft burner can be as much as ten times the price of the simple atmospheric burner.

For most kilns atmospheric burners provide excellent performance. Nearly all potters responding to my questionnaire use this type. At the University we fire all of our kilns with a simple Bunsen type atmospheric burner. This burner presents no problems in obtaining the desired temperature, or kiln atmosphere. Therefore, on the recommendations of the potters questioned, and the excellent performance witnessed at the University, I have chosen to use two Number 186 Venturi-type atmospheric burners. This burner produces fifty thousand B.T.U.'s per hour at low gas pressure, and sixty thousand B.T.U.'s per hour at high gas pressure.

The burners used to fire the kiln under discussion are equipped with a primary air control. Due to the fact that the flame is directed down an enclosed passage, there may be problems in controlling a reduction by merely closing the damper. Using the primary air control the oxygen and gas mixture can be regulated with the burner. This method of reducing will give the operator complete control of the kiln atmosphere.

The question of how many B.T.U.'s are needed to heat a given firing chamber is a mystery to most potential kiln builders. It is often solved either by trial-and-error, or by using an oversized burner. Either method can be expensive. Therefore, a simple formula has been developed to follow in this situation.

It has been discovered that most successful kilns utilize about six thousand B.T.U.'s per cubic foot of firing chamber space. By multiplying the volume of the kiln's firing chamber (eighteen cubic feet) by six thousand B.T.U.'s per hour it will take about one-hundred and eight thousand B.T.U.'s per hour to heat the firing chamber to a minimum of cone six which is two-thousand two-hundred and thirty-two degrees Fahrenheit. Under normal conditions this temperature can be reached in eight to ten hours after an over-night preheating. By using this formula, the number of B.T.U.'s for a fifteen to twenty-five cubic foot down-draft kiln can be computed.

The gas burners are manufactured by Johnson Gas Appliance Company of Cedar Rapids, Iowa.

CHAPTER X

PROBLEMS AND SUGGESTED SOLUTIONS IN THE CONSTRUCTION OF THE ANGLE-IRON FRAME AND PLACEMENT OF SPY HOLES

There is no provision made for spy holes in the door, because this particular kiln design rules out the idea of placing cones near the door. There are two reasons for this: (1) By placing the cones near the door the readings are not accurate. This is due to the fact that the door area tends to be one of the coolest parts of the kiln, along with the extreme rear near the exhaust vent. (2) By placing the cones near the door the reading must be taken near the edge of the firing chamber. This does not give an accurate reading of the interior temperature. For these reasons there are provisions made to install four permanent spy holes, two on each side. A permanent spy hole is used in most commercially-built kilns. Placing the spy holes on the sides situates the cones nearer the interior of the kiln. This gives more accurate readings. Also, it should be noted that the front location of the heat vents makes it unadvisable to place the cones near the door.

One spy hole should be placed at the level of the first shelf, and the other about eight to ten inches from the roof. For ideal results the spy holes should be off-set on both sides. This will provide an excellent view of what is happening inside of the kiln during firing.

After the kiln's construction is completed, the entire structure is stablized by a steel rod and angle iron frame. The frame consists of three-inch angle irons placed at all four corners and bolted into place by steel rods running from corner to corner. The angle iron supports protect the corners from being damaged, as well as giving the entire structure stability. A word of caution should be mentioned concerning the first firings. When the kiln is fired, expansion occurs, necessitating rod adjustment in order that the entire structure may expand to its limits. When the desired temperature is reached, the bolts are tightened and left in that position for the life of the kiln.

CHAPTER XI

SUMMARY AND CONCLUSIONS

In designing any kiln, simplicity is the key to success. The design discussed in this paper is a eighteen cubic-foot box lined with high-temperature fire brick and insulated with a soft porous insulation brick. The fire boxes are completely independent of the general kiln structure. This is to give them versatility should they deteriorate and have to be changed.

The idea behind forcing the gas under the floor is to heat it sufficiently in order to eliminate a potentially cold floor. Cold floors are a common characteristic of the down-draft kiln.

This kiln design calls for a rather deep exhaust passage to insure a smooth downward pull which should help in keeping the entire kiln temperature equal. The exhaust vent is smaller than the passage and chimney to insure positive draft control.

It has been determined that one hundred and eight thousand B.T.U.'s would be sufficient to fire the kiln at stoneware temperatures from cone six to cone ten. This figure was arrived at by multiplying six thousand B.T.U.'s (a predetermined figure) which heats one cubic foot, by the total volume of eighteen cubic feet in the firing chamber.

If care is taken in construction and design, the kiln should work well. However, it must be considered that no matter how carefully the kiln is constructed, some adjustments will have to be made in the first few firings. Each kiln has its own personality, and the builder must be aware of this.

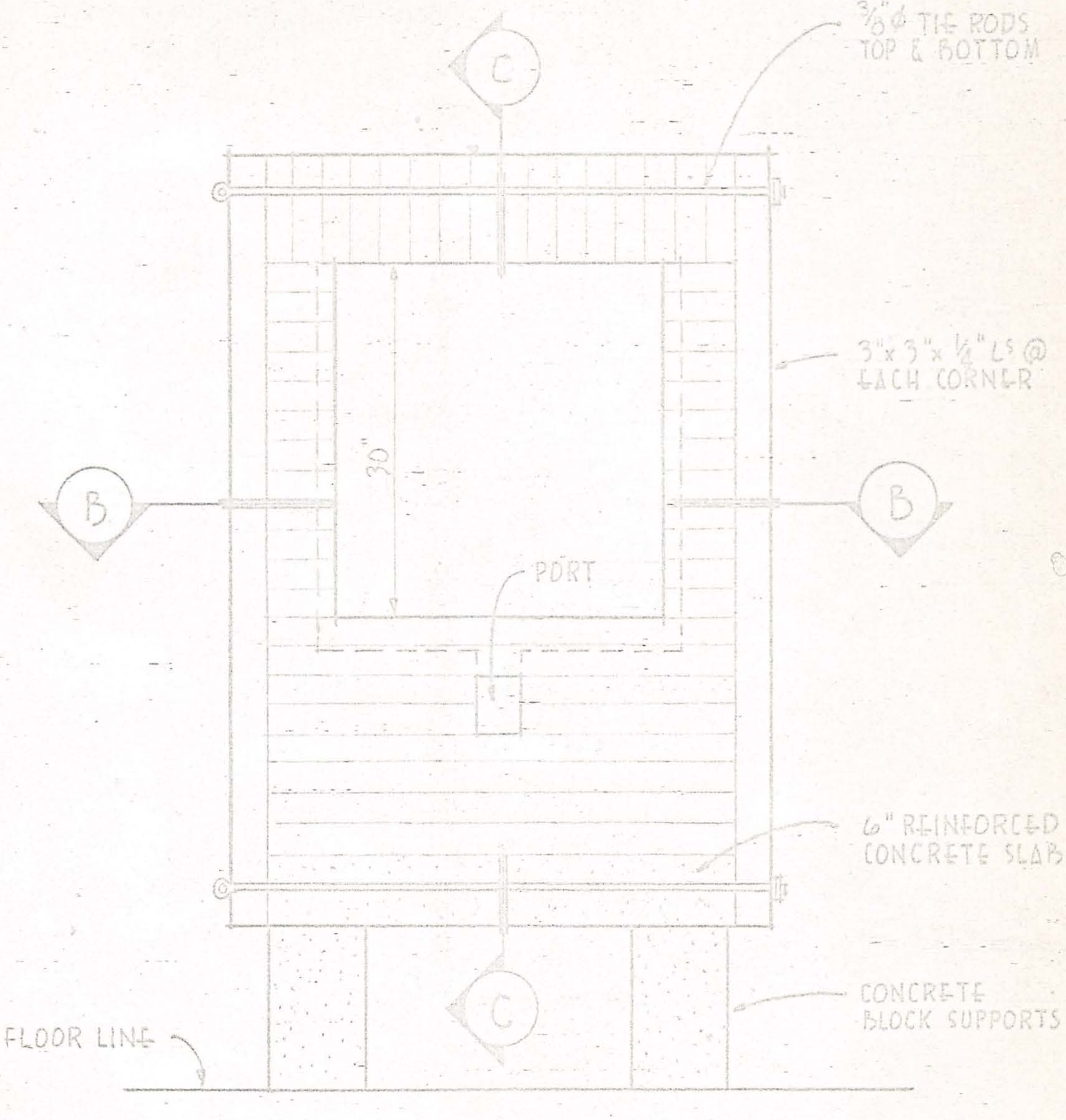
The first two or three firings should be slow to make sure that the entire kiln is dried out properly. If this is not done excessive cracking will occur. During the first firing, adjustments in the angle-iron frame and the brick roof must be made. Should these points be overlooked the brick will crack or buckle under the strain of expansion.

This kiln is particularly exciting because of the numerous variations which can be made from the basic design. It can be fired using one to four burners depending on the kiln's size. By making slight alterations in the basic design the kiln can be made to fit nearly any space. Because there are no baffle walls maximum use is made of the available space in the firing chamber. The roof arrangement is such that it can be raised to enlarge the interior, within limits. Also, because of its simple design and construction the entire kiln can easily be dismantled and reassembled in a new situation. Having these attributes, the kiln would seem to be very versatile. Its only real limitation may lie in its use as a salt kiln--primarily because of the lack of a direct flame in the firing chamber.

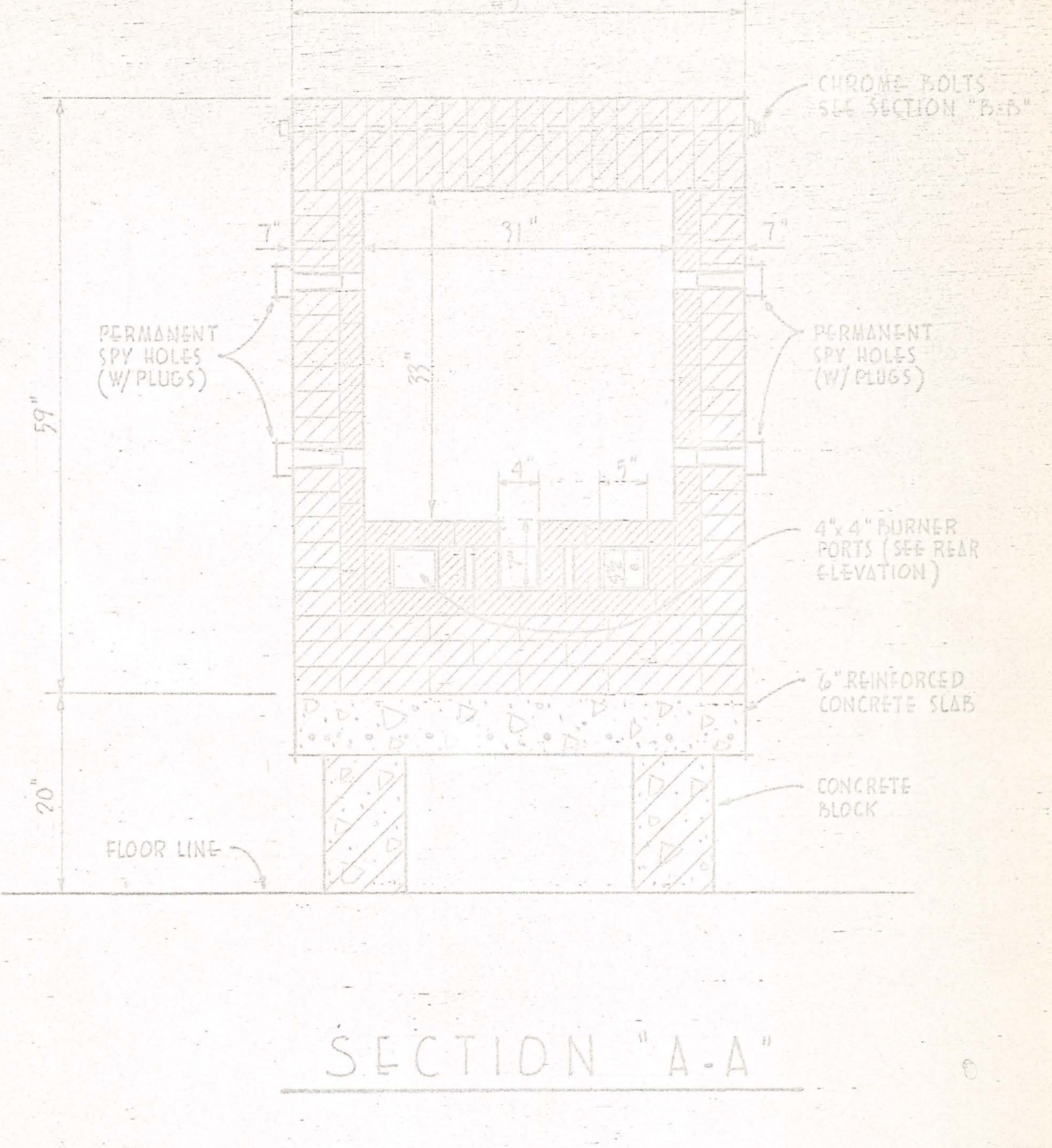
In regard to suggestions for further study, it has occured to me that some work might be done with castable linings for the interiors of kilns. This could lead to the development of new and easier methods of construction. The most important characteristic of a castable refractory should be its ability to withstand the stresses and strains of stoneware temperatures without cracking and deteriorating.

In using the time-tested kiln-building techniques and materials, along with the contributions of modern technology, the prospects of further kiln construction are exciting and almost unlimited.

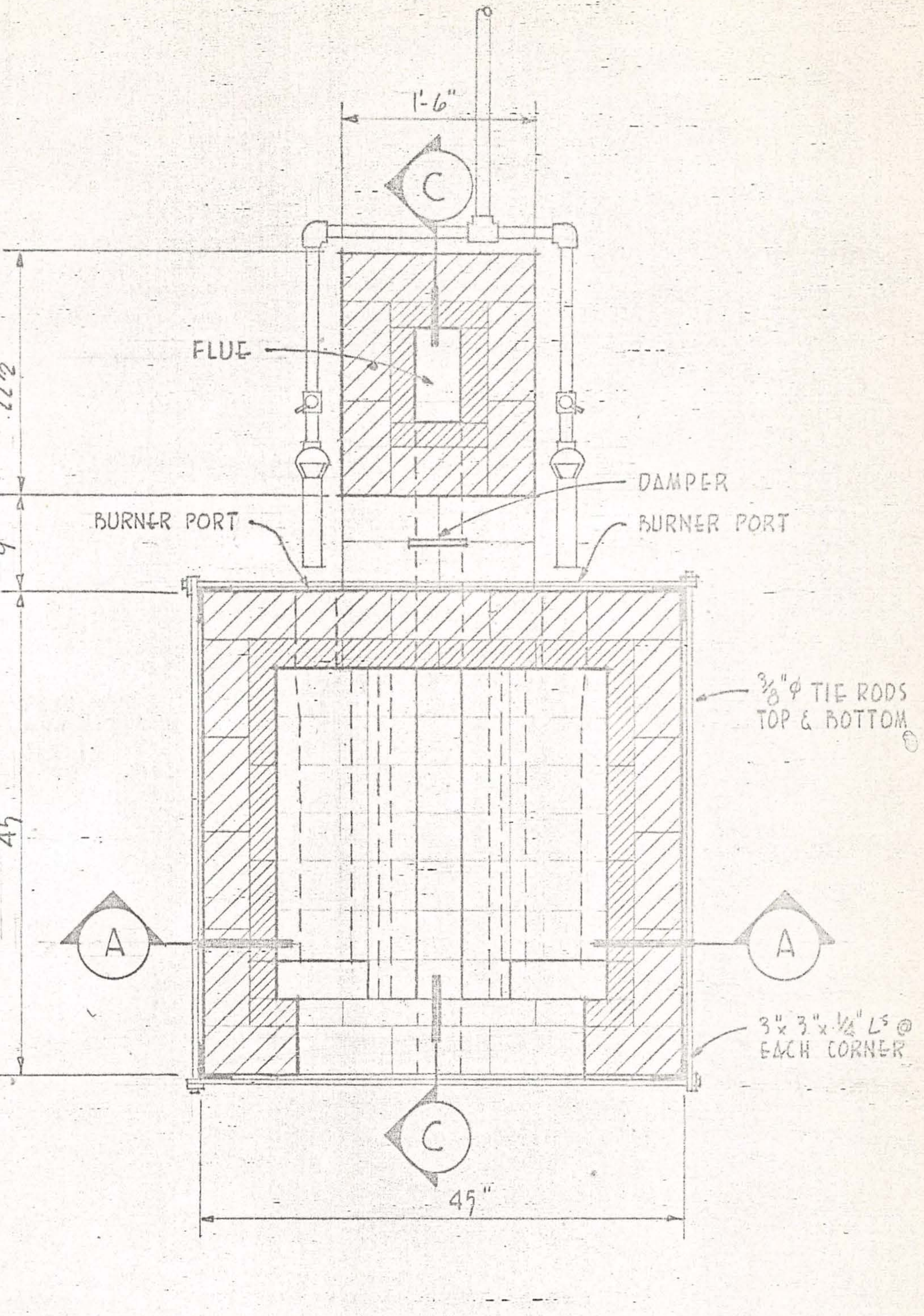
Appendix A



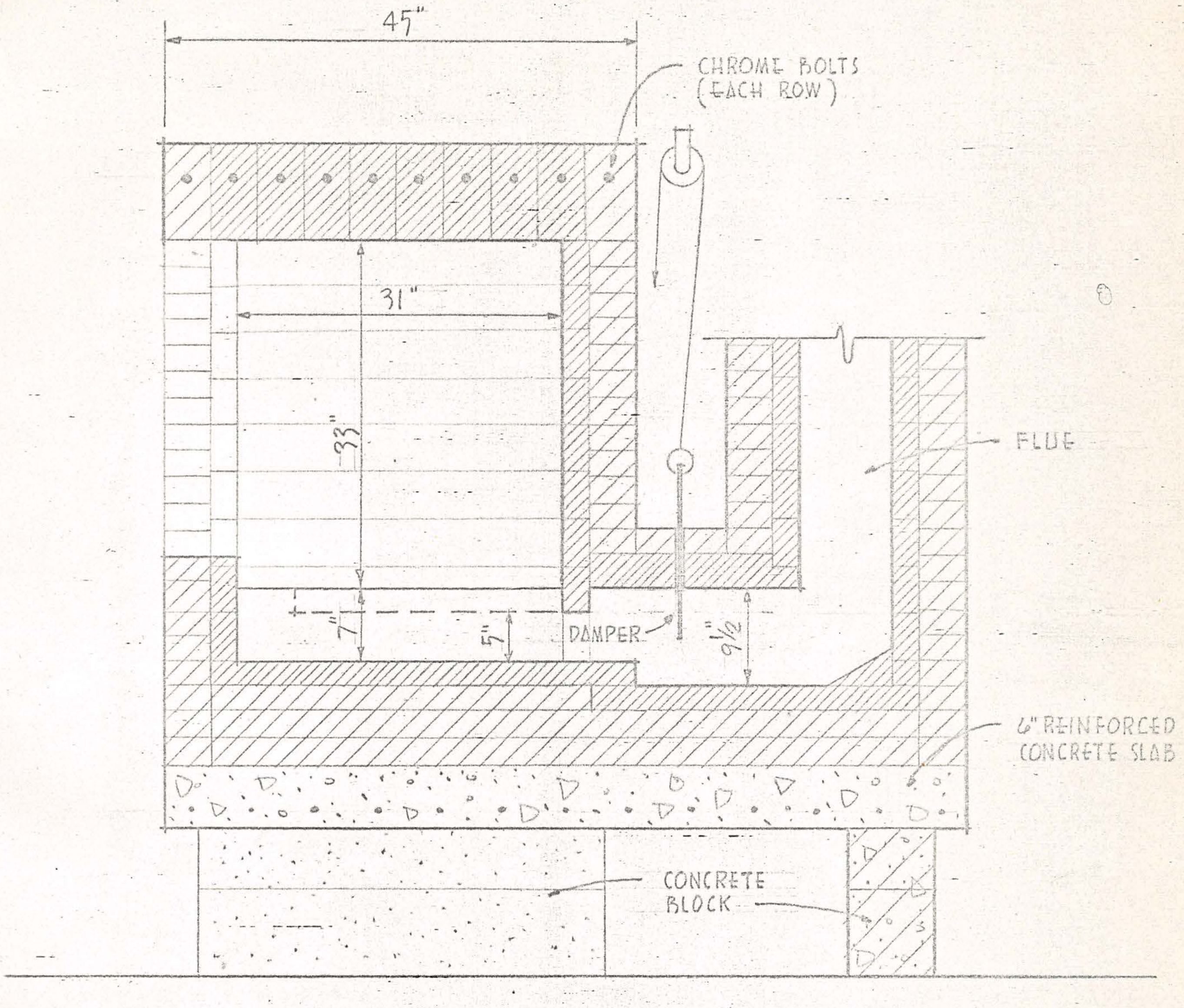
FRONT ELEVATION


45"
CHROME BOLTS
SEE SECTION "B-B"
7"
31"
7"
PERMANENT
SPY HOLES
(W/ PLUGS)
PERMANENT
SPY HOLES
(W/ PLUGS)
33"
59"
4"
5"
4" x 4" BURNER
PORTS (SEE REAR
ELEVATION)
6" REINFORCED
CONCRETE SLAB
CONCRETE
BLOCK
20"
FLOOR LINE

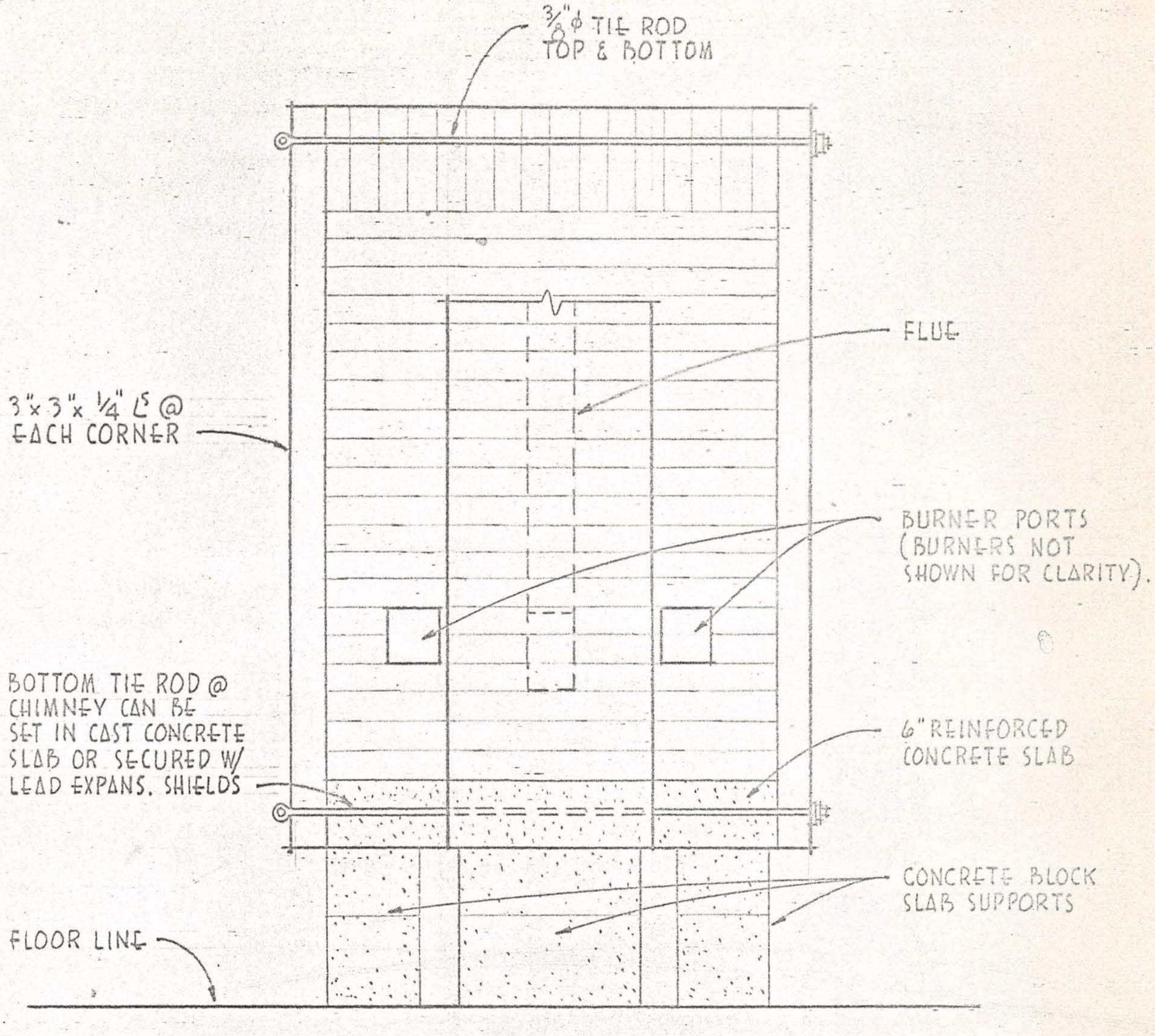
SECTION "A-A"


1'-6"
C
FLUE
22 1/2"
9"
45"
DAMPER
BURNER PORT
BURNER PORT
3/8"φ TIE RODS
TOP & BOTTOM
A
A
3"x 3"x 1/4" Ls @
EACH CORNER
C
45"

SECTION "B-B"


45"
CHROME BOLTS
(EACH ROW)
31"
33"
FLUE
7"
5"
DAMPER
9½"
6" REINFORCED
CONCRETE SLAB
CONCRETE
BLOCK

SECTION "C-C"



REAR ELEVATION

Appendix B

QUESTIONS CONCERNING KILN CONSTRUCTION AND FIRING CHARACTERISTICS

CONSTRUCTION:

1. What type of brick is used in the construction of your kiln, and also what is the temperature range of the inside wall and of the outside insulation wall?

2. Do you use a direct draft or a hood to exhaust the kiln?

3. What is the total length of the stack?

4. If there are openings in the baffle wall, how many are on each side; and how many inches from the floor are they?

5. How large in diameter are the burner ports?

6. Where is the draft control located?

BURNERS:

1. What is the B.T.U. rating of the burners?

2. What type of burner is used? (Ex.: Bunsen)

3. How many burners do you use?

4. Are the burners forced or natural draft?

5. How many pounds of gas pressure do you have at the burner?

6. How many inches are the burners from the burner ports?

FIRING CHARACTERISTICS:

1. How many hours do you preheat the kiln, and to what cone do you generally fire?

2. How many hours does it take for you to complete a firing?

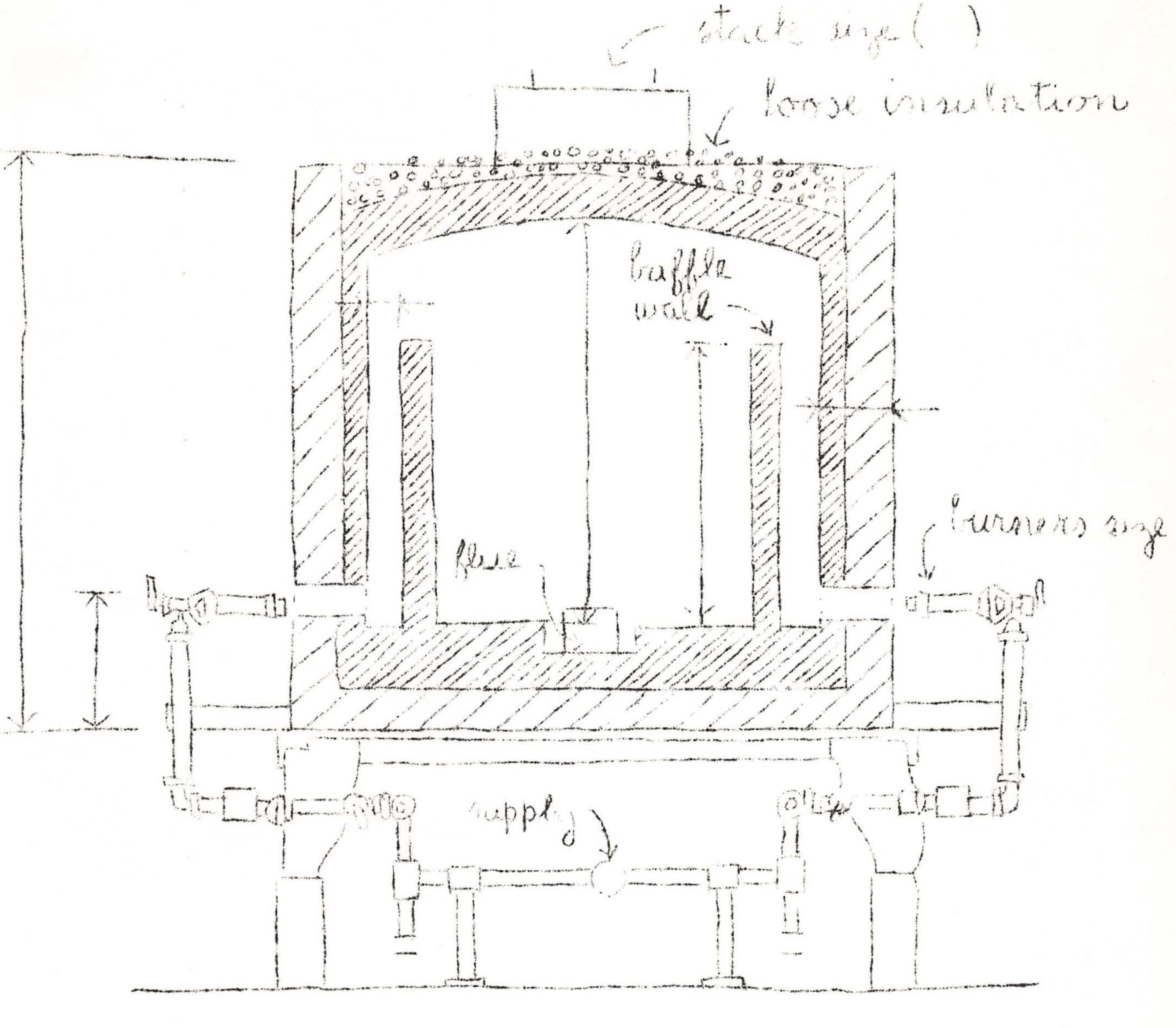
3. Does the kiln consistently have hot or cold spots and if so, where?

4. Does your kiln tend to be hotter at the top or the bottom, and do you have trouble equalizing it?

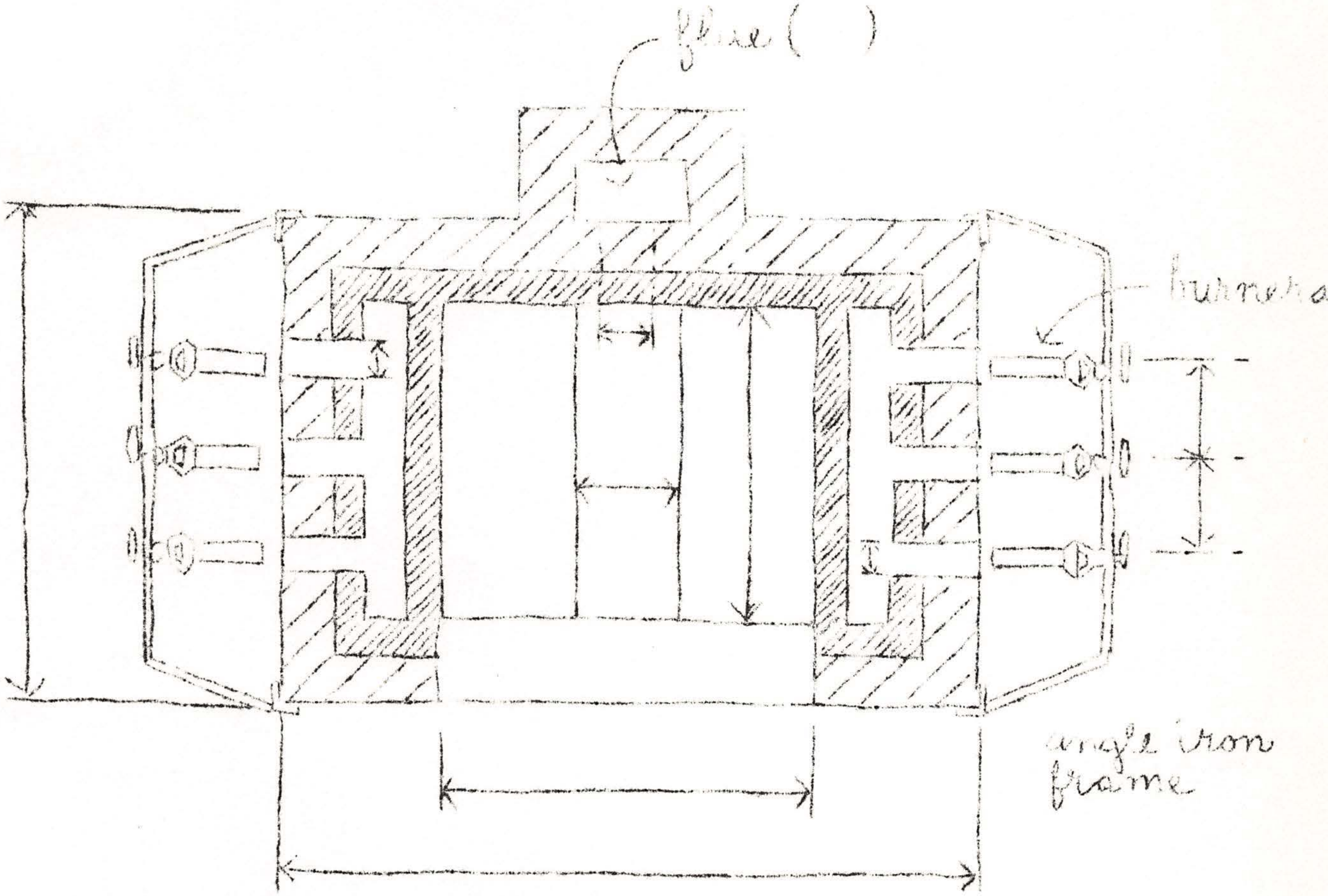
5. Do you favor a square or a deep rectangular or a wide rectangular design?

6. Is there any noticeable change in the firing characteristics in relation to the size and placement of the load?

7. If there is anything which I have not mentioned in this questionaire, and you feel that it would be important for a more complete coverage, I would appreciate your comments. If not, thank you very much for your cooperation. I know that the information which you have given me will help Mr. Nelson and myself in solving this problem.



Cross Section



Plan